Carnegie-Mellon University
Software Engineering Institute

Support Materials for

Language and System Support for Concurrent Programming

Support Materials SEI-SM-25

Carnegie Mellon University
Software Engineering Institute

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Gary Ford, editor
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The ideas and findings in this report should not be construed as an official DoD position. It is published in the interest of scientific and technical information exchange.

Review and Approval

This report has been reviewed and is approved for publication.

FOR THE COMMANDER

Charles J. Ryan, Major, USAF
SEI Joint Program Office

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Table of Contents

Examples of Concurrent Programs

Michael B. Feldman

The George Washington University

The first example is an implementation in each of four languages (Ada, Concurrent C, Co-Pascal, and occam) of the famous Dining Philosophers problem first stated by Dijkstra[1]. In this metaphorical statement of deadlock and resource allocation problems, five philosophers sit around a circular table, in the center of which is a infinitely large bowl of Chinese food. To the left and right of each philosopher is a single chopstick; each philosopher must try to acquire both chopsticks, eat for awhile, then put down the chopsticks and think for awhile; this cycle repeats for some total number of meals. (Dijkstra's original formulation used spaghetti and forks; we prefer the chopstick setting because most people can eat spaghetti with one fork.) The algorithm for chopstick selection must be chosen carefully, otherwise if all philosophers grab, say, their left chopsticks and refuse to yield them, all will starve!

The second example is one we have used with repeated success at The George Washington University, namely a "sort race" in which three different sorting methods are activated as processes. Each sort displays its progress in its "window" (usually a single row) on the terminal; mutual exclusion is necessary to protect the screen, which is a writable shared resource. We have found this example interesting and fun–there is a lot of screen activity, the problem being solved is obvious, and the three independent sorts serve as placeholders for any three independent applications contending for the processor and a shared data structure. In our comparative concurrency seminar, students must implement the sort race in the five different languages, starting from modules like sort subroutines, terminal drivers, process managers, etc., supplied by the teacher.

Machine-readable copies of these programs are available from the Software Engineering Institute. You may request a copy in either of the ways described below. Be sure to specify that you want the "Examples of Concurrent Programs" from support materials package SEI-SM-25.

1. **Electronic Mail**. Send your request to education@sei.cmu.edu on the Internet. The programs will be sent by electronic mail within a few days.

2. **Diskette**. A diskette containing the programs may be ordered from the SEI Software Engineering Curriculum Project. The cost is $10 and a check must

[1]Dijkstra, E. W. "Hierarchical Ordering of Sequential Processes." *Acta Informatica 1,* 115-138.

accompany your order. Two formats are available: IBM PC/AT diskette (5.25", double-sided, high-density, 1.2M byte) and Macintosh diskette (3.5", double-sided, 800K byte). Please specify the desired format.

Dining Philosophers in Ada

```
-- Dining Philosophers in Ada
-- Michael B. Feldman, The George Washington University
-- January 1990


with TEXT_IO, CALENDAR;
use CALENDAR;
procedure EAT is
  package INT_IO is new TEXT_IO.INTEGER_IO(INTEGER);
    task type CHOPSTICK is
      entry PICKUP;
      entry PUTDOWN;
    end CHOPSTICK;
    task SCREEN is
      entry PUT_LINE(S: STRING);
    end SCREEN;
    subtype NAME is STRING(1..`3);
    task type PHILOSOPHER is
      entry GIVE_BIRTH ( ID: NAME; who, one, two : integer );
    end PHILOSOPHER;

  CHOPSTICKS   : array (1..5) of CHOPSTICK;
  PHILOSOPHERS : array (1..5) of PHILOSOPHER;
  NAMES : constant array(1..5) of NAME :=
      ("Tony Hoare   ",
       "Nicky Wirth  ",
       "Eddy Dijkstra",
       "Jean Ichbiah ",
       "Narain Gehani");
  NO_MEALS : integer;
  START_TIME: duration;
  task body SCREEN is
    begin
      loop
        select
          accept PUT_LINE(S: STRING) do
            TEXT_IO.PUT_LINE(S);
          end PUT_LINE;
        or
          terminate;
        end select;
      end loop;
    end SCREEN;

  task body CHOPSTICK is
    begin
      loop
        select
          accept PICKUP;
        or
          terminate;
        end select;

        accept PUTDOWN;
      end loop;
    end CHOPSTICK;

  task body PHILOSOPHER is
      MY_NAME : NAME;
```

```
      first,second,identity : integer;
    begin
      select
        accept GIVE_BIRTH ( ID: NAME; who, one, two : integer ) do
          MY_NAME := ID;
          identity := who;
          first   := one;
          second := two;
          SCREEN.put_line("T = "
                   & integer'image(integer(seconds(clock)-START_TIME))
                   & " " & MY_NAME & " living and breathing");
        end GIVE_BIRTH;
      or
        terminate;
      end select;
      for x in 1..NO_MEALS loop
        CHOPSTICKS(first).PICKUP;
        CHOPSTICKS(second).PICKUP;
        SCREEN.put_line("T = "
                   & integer'image(integer(seconds(clock)-START_TIME))
                   & " " & MY_NAME & " eating with chopsticks"
                   & integer'image(first) & " "&integer'image(second)  );
        delay DURATION(2*identity);
        SCREEN.put_line("T = "
                   & integer'image(integer(seconds(clock)-START_TIME))
                   & " " & MY_NAME & " done");
        CHOPSTICKS(first).PUTDOWN;
        CHOPSTICKS(second).PUTDOWN;
      end loop;
      SCREEN.put_line(MY_NAME & " burp");
    end PHILOSOPHER;



begin
  SCREEN.put_line("How many meals do you want to eat?");
  INT_IO.get(NO_MEALS);
  TEXT_IO.NEW_LINE;
  START_TIME := seconds(clock);
  PHILOSOPHERS(2).GIVE_BIRTH(NAMES(2),2,2,3);
  PHILOSOPHERS(5).GIVE_BIRTH(NAMES(5),5,1,5);
  PHILOSOPHERS(3).GIVE_BIRTH(NAMES(3),3,3,4);
  PHILOSOPHERS(4).GIVE_BIRTH(NAMES(4),4,4,5);
  PHILOSOPHERS(1).GIVE_BIRTH(NAMES(1),1,1,2);
end EAT;
```

Dining Philosophers in Concurrent C

```
/* Non-deadlocking Dining Philosophers in Concurrent C
/* Adapted from
   Gehani and Roome, "The Concurrent C Programming Language" by
   Prof. Michael Feldman
   The George Washington University
   February 1990
*/

process spec fork()
{
   trans void pickUp(), putDown();
};
process body fork()
{
   for (;;) {
      accept pickUp();
      accept putDown();
   }
}


process spec philosopher(int id,
                         process fork left,
                         process fork right);
#define LIMIT 10
process body philosopher(id, left, right)
{
   int nmeal;
   printf("Phil. %d: *alive*\n", id);
   for (nmeal = 0; nmeal < LIMIT; nmeal++) {
      /*think; then enter dining room */
        delay 2*(5-id);
      /*pick up forks*/
        right.pickUp();
        left.pickUp();
      /*eat*/
        printf("Phil. %d: *eating*\n", id);
        delay 2*(5-id);
        printf("Phil. %d: *burp*\n", id);
      /*put down forks*/
        left.putDown();
        right.putDown();
      /*get up and leave dining room*/
   }
   printf("Phil. %d: That's all, folks!\n", id);
}

main()
{
   process fork f[5]; int j;

 /*create forks, then create philosophers*/
   for (j = 0; j < 5; j++)
      f[j] = create fork();
   for (j = 0; j < 5; j++)
      create philosopher(j, f[j], f[(j+1) % 5]);
   create philosopher(4, f[0], f[4]);
}
```

Dining Philosophers in Co-Pascal

```
program  diners (input, output);

{ This is the Dining Philosophers written in Co-Pascal       }
{ Prof. Michael B. Feldman, The George Washington University }
{ January 1990                                               }

const  life = 5;
type semaphore = integer;
var chopsticks: array[0..3] of semaphore;
 room: semaphore;
 screen: semaphore;
 which: integer;

procedure delay(HowLong: integer);
 var count: integer;
begin
 count := 1;
 while count < HowLong do
  count := count+1;
end {delay};


procedure think(WhoAmI: integer);
begin
 wait(screen);
 writeln('Philosopher ',WhoAmI:2,' ..Hmmm...');
 signal(screen);
 delay(10*(WhoAmI+1));

end {think};

procedure eat(WhoAmI: integer; meals:integer);
begin
 wait(screen);
 writeln('Philosopher ',WhoAmI:2,' eating meal ', meals:3, ' ..Slurp slurp...');
 signal(screen);
 delay(100*(WhoAmI+1));

end {eat};

procedure philosopher(WhoAmI: integer);
 var meals: integer;
begin
 wait(screen);
 writeln('philosopher ',WhoAmI:2, ' breathing');
 signal(screen);

 for meals := 1 to life do
 begin
  think(WhoAmI);
  wait(room);
  wait(chopsticks[WhoAmI]);
  wait(chopsticks[(WhoAmI+1) mod 4]);
  eat(WhoAmI,meals);
  signal(chopsticks[WhoAmI]);
  signal(chopsticks[(WhoAmI+1) mod 4]);
  signal(room);
 end;
```

```
 wait(screen);
 writeln('philosopher ',WhoAmI:2, ' burp');
 signal(screen);

end {philosopher};

begin {main}
 room := 3;
 screen := 1;
 for which := 0 to 3 do
  chopsticks[which] := 1;
 cobegin
  philosopher(0);
  philosopher(1);
  philosopher(2);
  philosopher(3);
 coend;

end {diners}.
```

Dining Philosophers in occam

```
--
-- Implementation in occam of the dining philosophers problem.
-- Distributed with University of Loughborough occam for UNIX systems.
-- execute with -c option to get cursor control
--
-- A number of philosophers spend their life either thinking or eating.
-- Unfortunately there is only one bowl of spaghetti and there is only one fork
-- per philosopher, but two forks are needed to eat the food.
-- A philosopher waits for a neighbour to relinquish a fork if needed.
-- The system can deadlock (the philosophers can starve) but it is difficult
-- to prove it.
-- The system is simulated by making the philosophers eat and think for random
-- times, a cursor addressible screen is used for output showing the current
-- status.
--
DEF Enter = 0,Exit = 1 :
DEF Grab = 0,Replace = 1,To.Right = 2,To.Left = 3 :
DEF Grabbed = 0,PutBack = 1 :
DEF Thought = 0,Consume = 1,Queuing = 2 :
--
-- Number of philosophers - may be between 1 and 8
--
DEF number.of.philosophers = 5:
CHAN Door [number.of.philosophers],Request.Fork [number.of.philosophers*2] :
CHAN phil.info [number.of.philosophers],Fork.info [number.of.philosophers] :
CHAN room.info :
EXTERNAL PROC random (VALUE m,VAR n) :
--
-- Sit and think outside the room for a random time interval
--
PROC Think (VALUE n) =
  VAR think.time :
  SEQ
    -- Thinking
    phil.info [n] ! Thought
    random (90,think.time)
    WAIT 40 + think.time
    -- Finished thinking - now waiting to eat.
    phil.info [n] ! Queuing :
--
-- Have grabbed two forks - signal eating and wait for a random interval
--
PROC Eat (VALUE n) =
  VAR eat.time :
  SEQ
    phil.info [n] ! Consume
    random (80,eat.time)
    WAIT 50 + eat.time  :
--
-- Define action of philosopher - think,enter room,pick up left then
-- pick up right fork and eat, finally leave the room to think again.
--
PROC Philosopher (VALUE n, CHAN left,right) =
  WHILE TRUE
    SEQ
      Think (n)
      Door [n] ! Enter
      left ! Grabbed
      right ! Grabbed
```

```
      Eat (n)
      left ! PutBack
      right ! PutBack
      Door [n] ! Exit :
--
-- Room - keep account of how many philosophers
-- there are eating or waiting to eat.
--
PROC Room =
  VAR action,number.in :
  SEQ
    number.in := 0
    WHILE TRUE
      SEQ
        room.info ! number.in
        ALT m = [0 FOR number.of.philosophers]
          Door [m] ? Action
            IF
              Action = Enter
                number.in := number.in + 1
              TRUE
                number.in := number.in - 1 :
--
-- Control of each fork - can be picked up by either side but then must
-- wait until it is put down.
-- Tell the display process the new status of the fork.
--
PROC Fork (VALUE n,CHAN left,right) =
  WHILE TRUE
    ALT
      left ? ANY
        SEQ
          Fork.Info [n] ! To.Left ; Grab
          left ? ANY
          Fork.Info [n] ! To.Left ; Replace
      right ? ANY
        SEQ
          Fork.Info [n] ! To.Right ; Grab
          right ? ANY
          Fork.Info [n] ! To.Right ; Replace :
--
-- Show animated display of what is happening
--
EXTERNAL PROC str.to.screen (VALUE s []) :
EXTERNAL PROC num.to.screen.f (VALUE n,f) :
EXTERNAL PROC Goto.x.y (VALUE x,y) :
EXTERNAL PROC clear.screen :
PROC Display =
  VAR Action,Which,Person,How.Many.In :
  SEQ
    clear.screen
    Goto.x.y (0,2)
    str.to.screen ("Number of philosophers in room : ")
    SEQ n = [0 FOR number.of.philosophers]
      SEQ
        Goto.x.y (0,(n*3)+4)
        str.to.screen ("Philosopher ")
        num.to.screen.f (n,3)
    WHILE TRUE
      ALT
        room.info ? How.Many.In
          SEQ
            Goto.x.y (33,2)
            num.to.screen.f (How.Many.In,2)
```

```
        ALT m = [0 FOR number.of.philosophers]
          ALT
            phil.info [m] ? Action
              IF
                Action = Thought
                  SEQ
                    Goto.x.y (20,(m*3)+4)
                    str.to.screen ("Thinking  ")
                Action = Queuing
                  SEQ
                    Goto.x.y (20,(m*3)+4)
                    str.to.screen ("Waiting   ")
                TRUE
                  SEQ
                    Goto.x.y (20,(m*3)+4)
                    str.to.screen ("Eating    ")
            Fork.Info [m] ? Which
              SEQ
                IF
                  Which = To.Left
                    SEQ
                      Person := m
                      Goto.x.y (50,(Person*3)+4)
                  TRUE
                    SEQ
                      Person := (m+1)\number.of.philosophers
                      Goto.x.y (55,(Person*3)+4)
                Fork.Info [m] ? Action
                IF
                  Action = Grab
                    str.to.screen ("!")
                  Action = Replace
                    str.to.screen (" ") :
--
-- Define parallel processes
-- There are two channels from philosophers to each fork.
-- The fork process ensures it is in the hand of one philosopher only.
--
PAR
  Room
  Display
  PAR n = [0 FOR number.of.philosophers]
    PAR
      Philosopher (n,Request.Fork [n*2],Request.Fork [(n*2)+1])
      Fork (n,Request.Fork [(n*2)+1],Request.Fork
[((n*2)+2)\(number.of.philosophers*2)])
```

Sorting Algorithm Race in Ada

```
WITH TEXT_IO; USE TEXT_IO;
WITH VT100; USE VT100;  -- this package is shown after the main program

PROCEDURE SortRace IS

--                          SortRace in Ada
--
--                           F. C. Hathorn
--                             CS - 358
--                              5/6/87


  PACKAGE Int_IO IS NEW Integer_IO(Integer);

   MaxLimit: CONSTANT := 34;
   Line1: CONSTANT    := 8;
   Line2: CONSTANT    := 12;
   Line3: CONSTANT    := 16;

   SUBTYPE ValueType IS CHARACTER;
   TYPE Vector    IS ARRAY (0..MaxLimit) OF ValueType;

   V:        Vector;
   Limit:    Integer;

   TASK Bubble_Sort is
      ENTRY GoAhead;
   END Bubble_Sort;

   TASK Insert_Sort is
      ENTRY GoAhead;
   END Insert_Sort;

   TASK Heap_Sort is
      ENTRY GoAhead;
   END Heap_Sort;

   TASK Screen is
      Entry ClearScreen;
      Entry PutAt(column, row: INTEGER; c: ValueType);
   END Screen;


-----------------------------------------------------------------------------
-- Put Vector
-- This procedure displays a vector on the screen at a given row
--
-----------------------------------------------------------------------------
   PROCEDURE PutVect(S: Vector; Row: INTEGER) IS
      BEGIN
        FOR i IN  1..Limit   LOOP
           Screen.PutAt(i+1,Row,S(i));
        END LOOP;
      END PutVect;


-----------------------------------------------------------------------------
-- Swap                                                                    --
-- This procedure exchanges two integer variable values.                   --
```

```
--
 --
--------------------------------------------------------------------------
 PROCEDURE Swap(x,y: IN OUT ValueType; i,j, row: INTEGER) IS
   Temp: ValueType;
   BEGIN
     Temp := x;
     x := y;
     y := Temp;
     Screen.PutAt(i+1,row,x);
     Screen.PutAt(j+1,row,y);
   END Swap;


--------------------------------------------------------------------------
-- Task Screen                                                          --
-- Code to write to the screen.  Two entries are provided, ClearScreen  --
-- which clears the screen and PutAt which writes one character.
 --
--------------------------------------------------------------------------
     TASK BODY Screen IS

     BEGIN
       LOOP
          SELECT
            ACCEPT ClearScreen DO
              VT100.ClearScreen;
            END ClearScreen;
          OR
            ACCEPT PutAt(column, row: INTEGER; c: ValueType) DO
                VT100.SetCursorAt(column,row); put(c);
            END PutAt;
          OR
            TERMINATE;
          END SELECT;
       END LOOP;
     END Screen;


--------------------------------------------------------------------------
-- Task Bubble Sort                                                     --
-- Code provided by Professor M.B. Feldman and modified slightly to sort  --
-- from 1..Limit rather than 0..Limit.
 --
--------------------------------------------------------------------------
   TASK BODY Bubble_Sort IS

   MyV: Vector;
   MyRow: Integer := Line1;
   CurrentBottom: INTEGER;
   AnotherPassNeeded: BOOLEAN;
   Top: INTEGER;

   BEGIN   --Bubble_Sort
     Accept GoAhead;
     PutVect(V,MyRow);
     MyV := V;
     Top := 1;
     CurrentBottom := Limit;
     AnotherPassNeeded := TRUE;
     WHILE AnotherPassNeeded AND (CurrentBottom > 1) LOOP
        AnotherPassNeeded := FALSE;
        FOR Current IN  Top .. CurrentBottom-1 LOOP
           IF  (MyV(Current+1) < MyV(Current)) THEN
```

```
            Swap(MyV(Current+1),MyV(Current),Current+1,Current,MyRow);
            AnotherPassNeeded := TRUE;
          END IF;
          if (current+1 = currentbottom) THEN
            Screen.PutAt(CurrentBottom+1, MyRow+1, '<');
          END IF;
        END LOOP;
        CurrentBottom := CurrentBottom - 1;
      END LOOP;
      Screen.PutAt(CurrentBottom+1, MyRow+1, '*');
    END Bubble_Sort;


-----------------------------------------------------------------------------
-- Task Insertion Sort                                                     --
-- This task performs an insertion sort on the input array.               --
--
 --
-----------------------------------------------------------------------------
TASK BODY Insert_Sort IS

MyV: Vector;
MyRow: Integer := Line2;
j:       integer;            --pointer into sorted array
insert:  valuetype;          --current key being inserted

begin   --Insert_Sort
  Accept GoAhead;
  PutVect(V, MyRow);
  MyV := V;
  MyV(Limit+1) := 'z';                  --initialize last + 1th element
  Screen.PutAt(Limit+1, MyRow+1, '<');   --mark last element as sorted
  FOR i IN REVERSE 1..Limit-1 LOOP      --insert elements limit-1..1 into
    insert := MyV(i);                   --save current key
    j := i + 1;
    WHILE (insert > MyV(j)) LOOP        --shift larger keys up
       MyV(j-1) := MyV(j);
       Screen.PutAt(j, MyRow, MyV(j));
       j := j + 1;
    END LOOP;
    MyV(j-1) := insert;                 --insert current key in proper place
    Screen.PutAt(j, MyRow, insert);
    Screen.PutAt(i+1, MyRow+1, '<');
  END LOOP;
  Screen.PutAt(2, MyRow+1, '*');
end Insert_Sort;


-----------------------------------------------------------------------------
-- Task Heap Sort                                                          --
-- This task sorts the input key array using the heap sort algorithm.     --
-- The input array is treated as a binary tree when building the heap.
 --
-----------------------------------------------------------------------------
TASK BODY Heap_Sort IS

MyV: Vector;
MyRow: Integer := Line3;

Procedure Adjust(t: IN OUT Vector; root, Lmt: integer) IS
-- adjust is used to adjust a heap whose left and right trees are heaps, but
-- whose root may be smaller than its left or right child

    j:          integer;    --child pointer
```

```
    key:        ValueType;  --key element
    done:       boolean := FALSE;    --adjustments done flag
  BEGIN
    key := t(root);             --save root key
    j := 2 * root;              --calculate child pointer
    WHILE ((j <= Lmt) and not done) LOOP
       IF (j < Lmt) THEN        --find largest child
          if (t(j) < t(j+1)) THEN j := j + 1; END IF;
       END IF;
       IF (key >= t(j)) THEN
          done := TRUE;         --done if child smaller than root
       ELSE                     --otherwise move child up
          t(j / 2) := t(j);
          Screen.PutAt(j / 2 + 1, MyRow, t(j));
          j := 2 * j;
       END IF;
    END LOOP;
    t(j / 2) := key;        --insert root in correct position
    Screen.PutAt(j / 2 + 1, MyRow, key);
  END Adjust;

BEGIN
-- main section of code for heap sort
  Accept GoAhead;
  PutVect(V, MyRow);
  MyV := V;
--convert the input array into a heap
  FOR i IN REVERSE  1..(Limit / 2) LOOP
     adjust(MyV, i, Limit);
  END LOOP;
  FOR i IN REVERSE 1..(Limit-1) LOOP   --pick off first element n-1 times
     swap(MyV(1), MyV(i+1), 1, i+1, MyRow);    --swap with last element
     Screen.PutAt(i+2, MyRow+1, '<');
     adjust(MyV, 1, i);                --readjust heap less last element
  END LOOP;
  Screen.PutAt(2, MyRow+1, '*');
END Heap_sort;


BEGIN
   V := " ZzYyXxWwVvUuTtSsRrQqPpOoNnMmLlKkJj";
   V(0)  := '<';
   V(34) := '<';
   Screen.ClearScreen;
   Screen.PutAt(1, Line1-3, ' ');
   Put_Line("SORT RACE - in Ada");
   Put("Enter Number of Keys to Sort (3-33): ");
   Int_IO.Get(Limit);
   IF (Limit < 3) OR (Limit > 33) THEN
      Limit := 10;
      Put(ASCII.BEL);
      Put_Line("Sorting 10 keys");
   END IF;
   Screen.PutAt(1, Line1-1, ' ');
   Put_Line("Bubble Sort");
   Screen.PutAt(1, Line2-1, ' ');
   Put_Line("Reverse Insertion Sort");
   Screen.PutAt(1, Line3-1, ' ');
   Put_Line("Heap Sort");
   Screen.PutAt(1,20,' ');
   Bubble_Sort.GoAhead;
   Insert_Sort.GoAhead;
   Heap_Sort.GoAhead;
END SortRace;
```

```
with TEXT_IO, MY_INT_IO; use  TEXT_IO, MY_INT_IO;
package VT100 is
   use ASCII;
----------------------------------------------------------
-- Procedures for drawing pictures of the solution on VDU.
-- ClearScreen and SetCursorAt are device-specific
----------------------------------------------------------

    SCREEN_DEPTH    : constant INTEGER  := 24;
    SCREEN_WIDTH    : constant INTEGER  := 80;

    subtype DEPTH is INTEGER range 1..SCREEN_DEPTH;
    subtype WIDTH is INTEGER range 1..SCREEN_WIDTH;


  procedure ClearScreen;

  procedure SetCursorAt( A: WIDTH; D : DEPTH);

end VT100;

-- ............................................................... --
with TEXT_IO; use  TEXT_IO;
package body VT100 is
  use ASCII;
----------------------------------------------------------
-- Procedures for drawing pictures on VT100
-- ClearScreen and SetCursorAt are trminal-specific
----------------------------------------------------------

  procedure ClearScreen is
  begin
      PUT( ESC & "[2J" );
  end ClearScreen;

  procedure SetCursorAt(A: WIDTH; D : DEPTH) is

  begin
             PUT( ESC & "[" );
        PUT( D, 1 );
       PUT( ';' );
       PUT( A, 1 );
       PUT( 'f' );
  end SetCursorAt;

end VT100;

-- ............................................................... --
```

Sorting Algorithm Race in Concurrent C

```
/*
--                      SortRace in Concurrent C
--
--                           F. C. Hathorn
--                             CS - 358
--                              5/5/87
*/

#define   MaxLimit   36
#define   Line1       6
#define   Line2      12
#define   Line3      18
#define   SMILE      '<'
#define   STAR       '*'
#define   BELL       '\7'
#define   VALUETYPE  char
#define   TRUE       1
#define   FALSE      0

   VALUETYPE      V[MaxLimit] = " ZzYyXxWwVvUuTtSsRrQqPpOoNnMmLlKkJj";
   int            Counter = 0;
   int            Limit;

   process spec    Bubble_Sort( VALUETYPE MyV[36], int MyRow, process Scrn );
   process spec    Insert_Sort( VALUETYPE MyV[36], int MyRow, process Scrn );
   process spec    Heap_Sort  ( VALUETYPE MyV[36], int MyRow, process Scrn );
   process spec    Scrn     ()
                   {
                    trans void PutAt(int, int, VALUETYPE);
                    trans void CheckWinner(int);
                    };

/*-----------------------------------------------------------------------
-- Bubble Sort                                                        --
-- Code Provided by Professor M.B. Feldman and modified slightly to sort   --
-- from 1..Limit rather than 0..Limit.                                --
-----------------------------------------------------------------------*/
   process body Bubble_Sort(MyV, MyRow, Screen)
      {
       int CurrentBottom;
       int AnotherPassNeeded;
       int Current, Top;

       PutVect(MyV,MyRow,Screen);
       Top = 1;
       CurrentBottom = Limit;
       AnotherPassNeeded = TRUE;
       while ((AnotherPassNeeded) && (CurrentBottom > 1)) {
          AnotherPassNeeded = FALSE;
          for (Current = Top; Current < CurrentBottom; Current++) {
             if (MyV[Current+1] < MyV[Current]) {
                Swap(&MyV[Current+1],&MyV[Current],Current+1,Current,MyRow,
                      Screen);
                AnotherPassNeeded = TRUE;
                }
             if (Current+1 == CurrentBottom)
                Screen.PutAt(CurrentBottom+1, MyRow+1, SMILE);
             }
```

```
        CurrentBottom = CurrentBottom - 1;
        }
      Screen.PutAt(CurrentBottom+1, MyRow+1, STAR);
      Screen.CheckWinner(MyRow + 1);
    } /* Bubble_Sort */

/*----------------------------------------------------------------------
-- Insertion Sort                                                     --
-- This process performs an insertion sort on the input array.        --
--                                                                    --
----------------------------------------------------------------------*/
   process body Insert_Sort(MyV, MyRow, Screen)
    {

      int j;            /* pointer into sorted array   */
      int i;
      VALUETYPE insert; /* current key being inserted  */

      PutVect(MyV, MyRow, Screen);
      MyV[Limit+1] = '\177';          /*initialize last + 1 element */
      Screen.PutAt(Limit+1, MyRow+1, SMILE);  /*mark last element as sorted */
      for (i=Limit-1; i>=1; i--) {    /*insert elements from limit-1..1 */
        insert = MyV[i];              /*save current key  */
        j = i + 1;
        while (insert > MyV[j]) {     /*shift larger keys up */
           MyV[j-1] = MyV[j];
           Screen.PutAt(j, MyRow, MyV[j]);
           j = j + 1;
           }
        MyV[j-1] = insert;            /*ins current key in proper loc */
        Screen.PutAt(j, MyRow, insert);
        Screen.PutAt(i+1, MyRow+1, SMILE);
        }
      Screen.PutAt(2, MyRow+1, STAR);
      Screen.CheckWinner(MyRow + 1);
    } /* Insert_Sort */

/*----------------------------------------------------------------------
-- Heap Sort                                                          --
-- This process sorts the input key array using the heap sort algorithm.  --
-- The input array is treated as a binary tree when building the heap.    --
----------------------------------------------------------------------*/
   process body Heap_Sort(MyV, MyRow, Screen)
    {
      int i;

      PutVect(MyV, MyRow, Screen);
      /* convert the input array into a heap */
      for (i=(Limit / 2); i>=1; i--)
               Adjust(MyV, i, Limit, MyRow, Screen);
      /* pick off first element n-1 times */
      for (i=(Limit-1); i>=1; i--) {
        Swap(&MyV[1], &MyV[i+1], 1, i+1, MyRow,
             Screen); /* swap w/ last element */
        Screen.PutAt(i+2, MyRow+1, SMILE);
        Adjust(MyV, 1, i, MyRow, Screen);     /* readjust heap */
        }
      Screen.PutAt(2, MyRow+1, STAR);
      Screen.CheckWinner(MyRow + 1);
    } /* Heap_sort */

/*----------------------------------------------------------------------
-- Process Screen                                                     --
-- This process controls access to the screen for writing once the sort   --
```

```
-- processes have been activated                                          --
-------------------------------------------------------------------------*/
   process body Scrn()
   {
    for (;;)          /* loop forever */
    select
    {
       accept PutAt(column, row, c)
         {
          SetCursorAt(column,row);
          putchar(c);
          } /* PutAt */
     or
       accept CheckWinner(row)
         {
          int i;
          Counter = Counter + 1;
          SetCursorAt(Limit+4, row);
          switch (Counter) {
             case 1: printf("WINNER!!!");
                     break;
             case 2: printf("SECOND!!");
                     break;
             case 3: printf("THIRD!");
                     SetCursorAt(1, Line3+4);
                     break;
             }
          for (i=Counter; i < 4; i++) putchar(BELL);
         } /* CheckWinner */
       or
         terminate;
    }
   }  /* Scrn */


   main()
   {
     VALUETYPE v1[MaxLimit], v2[MaxLimit], v3[MaxLimit];
     int i;

     process Scrn monitor;     /* screen monitor */
     process Bubble_Sort s1;
     process Insert_Sort s2;
     process Heap_Sort   s3;

     ClearScreen(), SetCursorAt();

     V[0]  = '\0';
     for (i=0; i<MaxLimit; i++)
         {v1[i] = V[i];  v2[i] = V[i];  v3[i] = V[i]; }
     SetCursorAt(1,1);
     ClearScreen();
     printf("SORT RACE - in Concurrent C\n");
     printf("Enter Number of Keys to Sort (3-33): ");
     scanf("%d%*c", &Limit);
     if ((Limit < 3) || (Limit > 33)) {
        Limit = 10;
        putchar(BELL);
        printf("Sorting only 10 Keys\n");
        }
     SetCursorAt(2, Line1-2);
     printf("Bubble Sort");
     SetCursorAt(2, Line2-2);
```

```
      printf("Reverse Insertion Sort");
      SetCursorAt(2, Line3-2,);
      printf("Heap Sort");

      /* start the screen monitor first */
      monitor = create Scrn();

      /* start the 3 sort processes */

      s1 = create Bubble_Sort(v1, Line1, monitor);
      s2 = create Insert_Sort(v2, Line2, monitor);
      s3 = create Heap_Sort(v3, Line3, monitor);
    } /* main */


    ClearScreen()
        {
         putchar('\033'); putchar('[');
         putchar('2'); putchar('J');
         } /* clearscreen */


    SetCursorAt(column, row)
    int column, row;
        {
         static  ASCIIOffset = 48;
         putchar('\033'); putchar('[');
         putchar((row    /   10) + ASCIIOffset);
         putchar((row    %   10) + ASCIIOffset);
         putchar(';');
         putchar((column /   10) + ASCIIOffset);
         putchar((column %   10) + ASCIIOffset);
         putchar('H');
        } /* SetCursorAt */


/*--------------------------------------------------------------------------
-- Put Vector                                                             --
-- This procedure copies the input vector into a local vector of the      --
-- calling task and displays that vector on the screen                    --
--------------------------------------------------------------------------*/
    PutVect(InV, row, Screen)
    VALUETYPE InV[];
    int row;
    process Scrn Screen;
        {
         int i;
         for (i = 1; i <= Limit; i++)  Screen.PutAt(i+1,row,InV[i]);
        } /* PutVect */


/*--------------------------------------------------------------------------
-- Swap                                                                   --
-- This procedure exchanges two integer variable values.                  --
--                                                                        --
--------------------------------------------------------------------------*/
    Swap(x, y, i, j, row, Screen)
    VALUETYPE *x, *y;
    int i, j, row;
    process Scrn Screen;
        {
         VALUETYPE temp;
         temp = *x;
         *x = *y;
```

```
     *y = temp;
     Screen.PutAt(i+1,row,*x);
     Screen.PutAt(j+1,row,*y);
    } /* Swap */


/*-----------------------------------------------------------------------
-- Adjust                                                                --
-- adjust is used to adjust a heap whose left and right trees are heaps,  --
-- but whose root may be smaller than its left or right child             --
------------------------------------------------------------------------*/

   Adjust(t, root, Lmt, MyRow, Screen)
   VALUETYPE t[];
   int root, Lmt, MyRow;
   process Scrn Screen;
      {
       int j;                   /* child pointer */
       VALUETYPE key;           /* key element */
       int done = FALSE;        /* adjustments done flag */

       key = t[root];           /* save root key */
       j = 2 * root;            /* calculate child pointer */
       while ((j <= Lmt) && !done) {
         if (j < Lmt) {         /* find largest child */
            if (t[j] < t[j+1]) j = j + 1; }
         if (key >= t[j])
            done = TRUE;        /* done if child smaller than root */
         else {                 /* otherwise move child up */
            t[j / 2] = t[j];
            Screen.PutAt(j / 2 + 1, MyRow, t[j]);
            j = 2 * j;
            }
         }
       t[j / 2] = key;        /* insert root in correct position */
       Screen.PutAt(j / 2 + 1, MyRow, key);
      } /* Adjust */
```

Sorting Algorithm Race in Co-Pascal

```
PROGRAM SortRace(INPUT,OUTPUT);

{ Sort Race - written by Roshan Thomas
                          The George Washington University
                          CSci 358 - Spring 1989

  Tested under Co-Pascal version 3.0 for IBM-PC.
  Be sure ANSI.SYS is installed before compiling this.

  demonstrates a concurrent sort race using Bubble Sort, Linear Insertion,
  and a non-recursive version of QuickSort }

   CONST Limit = 32;

   TYPE ValueType = CHAR;
        semaphore = INTEGER;
        Vector = ARRAY[0..Limit] OF ValueType;


   VAR V: Vector;
       i, Won: INTEGER;
       A: CHAR;
       Screen: semaphore;


   PROCEDURE ClearScreen;
      BEGIN
        Write(CHR(27)); Write('[');
        Write('2'); Write('J')
      END {ClearScreen};

  PROCEDURE SetCursorAt(column, row: INTEGER);
      BEGIN
        WriteLn;
        Write(CHR(27)); Write('[');
        Write(row:1);
        Write(';');
        Write(column:1);
        Write('H');
     END {SetCursorAt};

   PROCEDURE WriteAt(column, row: INTEGER; C: CHAR);
      BEGIN
        WAIT(Screen);
          SetCursorAt(column,row);
          Write(C);
        SIGNAL(Screen);
      END {WriteAt};

   PROCEDURE WriteVect(V: Vector; Row: INTEGER);
     VAR i: INTEGER;
   BEGIN
     FOR i := 0 TO Limit   DO BEGIN
       WriteAt(i+1,Row,V[i]);
     END;
     WriteLn;
   END {WriteVect};

   PROCEDURE CopyVect(VAR Dest: Vector; Source: Vector);
```

```
    VAR i: INTEGER;
  BEGIN
    FOR i := 0 TO Limit   DO BEGIN
      Dest[i] := Source[i];
    END;
  END {CopyVect};

PROCEDURE Swap(VAR x,y: ValueType; i,j, row: INTEGER);
    VAR Temp: ValueType;
  BEGIN
    Temp := x;
    x := y;
    y := Temp;
    WriteAt(i+1,row,x);
    WriteAt(j+1,row,y);
  END {Swap};


  PROCEDURE Bubble(MyV: Vector; MyRow: INTEGER);

    VAR
      CurrentBottom: INTEGER;
      AnotherPassNeeded: BOOLEAN;
      Top: INTEGER;
      Current: INTEGER;

  BEGIN
    Top := 0;
    CurrentBottom := Limit;
    AnotherPassNeeded := TRUE;
    WriteVect(MyV,MyRow);
    WHILE AnotherPassNeeded AND (CurrentBottom > 0) DO BEGIN
       AnotherPassNeeded := FALSE;
       FOR Current := Top TO CurrentBottom-1 DO BEGIN
          IF MyV[Current+1] < MyV[Current] THEN BEGIN
             Swap(MyV[Current+1],MyV[Current],Current+1,Current,MyRow);
             AnotherPassNeeded := TRUE;
          END;
       END;
       CurrentBottom := CurrentBottom - 1;
    END;
    IF Won = 0 THEN
    BEGIN
      WAIT(Screen);
      Won := 1;
      SetCursorAt(8,6);
      WRITELN('BUBBLE SORT HAS WON, SURPRISINGLY');
      SIGNAL(Screen);
    END;
  END {Bubble};


PROCEDURE LinearInsertionSort(LV: Vector; Lrow: INTEGER);

  VAR
    NewArrival: ValueType;
    Top: INTEGER;
    Bottom: INTEGER;
    CurrentBottom: INTEGER;
    current: INTEGER;
    position: INTEGER;

  BEGIN
   Top := 0;
```

```
  Bottom := Limit;
  FOR CurrentBottom := Top+1 TO Bottom DO BEGIN
    FOR current := CurrentBottom DOWNTO Top+1 DO BEGIN
        IF LV[current] < LV[current-1] THEN
           Swap(LV[current], LV[current-1], current, current-1, Lrow);
       { END;}
    END;
  END;

  IF Won = 0 THEN
  BEGIN
    WAIT(Screen);
    Won := 1;
    SetCursorAt(8,11);
    WRITELN('Linear Insertion Sort Has Won, Interestingly');
    SIGNAL(Screen);
  END;

 END;

PROCEDURE QuickSort(QV:Vector; Lrow: INTEGER);

    CONST m = 20;
    VAR
      i, j, l, r : INTEGER;
      x, w       : ValueType;
      s          : INTEGER;
      stack: array [1..40] of
             RECORD l,r: INTEGER END;

    BEGIN
      s := 1;
      stack[1]. l := 0; stack[1]. r := Limit;
      REPEAT {take top request from stack}
        l := stack[s]. l; r := stack[s]. r; s := s-1;
        REPEAT {split QV[l]...QV[r]}
          i := l;
          j := r;
          x := QV[(l+r) div 2];
          REPEAT
            WHILE QV[i] < x     DO i := i+1;
            WHILE x     < QV[j] DO j := j-1;
            IF i <= j THEN
            BEGIN
              Swap(QV[i], QV[j], i, j, Lrow);
              i := i+1; j := j-1;
            END;
          UNTIL i > j;
          IF i < r THEN
          BEGIN {stack request to sort right partition}
            s := s+1; stack[s]. l := i; stack[s]. r := r;
          END;
        r := j;
        UNTIL l >= r
      UNTIL s = 0;
      IF Won = 0 THEN
      BEGIN
        WAIT(Screen);
        Won := 1;
        SetCursorAt(8,16);
        WRITELN('QuickSort has WON!!!!!, PREDICTABLY');
        SIGNAL(Screen);
      END;
```

```
  END;

BEGIN
   V[0] := 'Z'; V[1] := 'z'; V[2] := 'Y'; V[3] := 'y';
   V[4] := 'X'; V[5] := 'x'; V[6] := 'W'; V[7] := 'w';
   V[8] := 'V'; V[9] := 'v'; V[10] := 'U'; V[11] := 'u';
   V[12] := 'T'; V[13] := 't'; V[14] := 'S'; V[15] := 's';
   V[16] := 'R'; V[17] := 'r'; V[18] := 'Q'; V[19] := 'q';
   V[20] := 'P'; V[21] := 'p'; V[22] := 'O'; V[23] := 'o';
   V[24] := 'N'; V[25] := 'n'; V[26] := 'M'; V[27] := 'm';
   V[28] := 'L'; V[29] := 'l'; V[30] := 'K'; V[31] := 'k';
   V[32] := 'J';

   Won := 0;
   Screen := 1;
   ClearScreen;
   SetCursorAt(10, 1);
   WRITELN('SORT RACE');
   SetCursorAt(8,3);
   WRITELN('BUBBLE  SORT');
   SetCursorAt(8,8);
   WRITELN('LINEAR INSERTION');
   SetCursorAt(8,13);
   WRITELN('QUICKSORT');

   FOR i:= 0 TO Limit DO
   BEGIN
    SetCursorAt(i+1,5);
    Write(V[i]);
    SetCursorAt(i+1,10);
    Write(V[i]);
    SetCursorAt(i+1,15);
    Write(V[i]);
   END;
   SetCursorAt(40,5);
   WRITELN;

   SetCursorAt(4,20);
   WRITELN('PRESS RETURN   T W I C E   TO BEGIN THE RACE');
   READLN(A);
   SetCursorAt(4,20);
   WRITELN('SORT  RACE  IN PROGRESS       ');

   cobegin
     Bubble(V,5);
     LinearInsertionSort(V,10);
     QuickSort(V,15);
   coend;
   WriteAt(1,20,' ');
END {SortRace}.
```

Sorting Algorithm Race in Modula-2

```
MODULE Race;

(* This module implements a sort race between 5 different sorting          *)
(* algorithms.  The 5 algorithms are executed (pseudo) concurrently and    *)
(* their progress is displayed on the screen.  This program requires       *)
(* that the ANSI.SYS display driver be resident on an IBM PC-type computer.*)
(* Tested using FST Modula-2 for IBM-PC, and Karlsruhe Modula-2 for Sun    *)

   FROM InOut IMPORT Write, WriteString;
   FROM vt100 IMPORT ClearScreen, SetCursorAt;  (* this module is shown    *)
                                                (* after main program below*)

   FROM Process IMPORT DefineProcess, (* Adds a procedure to the list of   *)
                                      (* processes to executed concurrently*)
                       Croak,         (* Allows a process to kill itself.  *)
                       GoToSleep,     (* Will cause temporary self-suspend.*)
                       StartSystem,   (* Starts concurrent execution.      *)
                       SIGNAL,        (* Semaphore TYPE.                   *)
                       Init,          (* Initializes a user semaphore.     *)
                       SEND,          (* Signal operation on semaphore.    *)
                       WAIT;          (* Wait operation on sempahore.      *)

   CONST Limit = 51;
   TYPE ItemType = CHAR;
        Vector = ARRAY[0..Limit] OF ItemType;

   VAR A1,A2,A3,A4,A5: Vector;
       Screen: SIGNAL;

   PROCEDURE WriteAt(row, col: CARDINAL; c: CHAR);
   BEGIN
     WAIT(Screen);
     SetCursorAt(col,row); Write(c);
     SEND(Screen);
   END WriteAt;

 (* Insertion sort ------------------------------------------------*)

   PROCEDURE Insertion;
     VAR i,j: CARDINAL;
         row: CARDINAL;
         item: ItemType;
         exit: BOOLEAN;
   BEGIN
     row := 5;
     WAIT(Screen);
     SetCursorAt(1,row); WriteString('Insertion:');
     SetCursorAt(14,row); FOR i:= 0 TO HIGH(A1) DO Write(A1[i]); END;
     SEND(Screen);

     FOR i:= 1 TO HIGH(A1) DO
       item := A1[i]; j:= i; exit:= FALSE;
       REPEAT
         DEC(j);
         IF (A1[j] > item) THEN
            A1[j+1]:= A1[j];
         ELSE
            A1[j+1]:= item; exit:= TRUE
```

```
          END;
          WriteAt(row,14+j+1,A1[j+1]);
        UNTIL (j = 0) OR (exit = TRUE);
        IF NOT exit THEN
           A1[0]:= item; WriteAt(row,14,A1[0])
        END;
      END; (* FOR i:= 1 to HIGH() *)
      Croak;
    END Insertion;

  (* Heap Sort procedure -------------------------------------------*)

    PROCEDURE HeapSort;
      VAR i   : CARDINAL;
          row : CARDINAL;
          swap: ItemType;

      PROCEDURE MakeHeap(low, high: CARDINAL);
        VAR j, k: CARDINAL;
            exit: BOOLEAN;
            item: ItemType;
      BEGIN
        j:= 2*low; item:= A2[low];
        exit:= FALSE;
        WHILE ((j <= high) AND (NOT exit)) DO
          IF (j < high) AND (A2[j+1] > A2[j])
             THEN j:= j+1;
          END;
          IF (item >= A2[j]) THEN
             exit:= TRUE;
          ELSE
             k:= j DIV 2;
             A2[k]:= A2[j];
             WriteAt(row,k+14,A2[k]); WriteAt(row,j+14,item);
             j:= 2*j;
          END;
        END;
        A2[j DIV 2]:= item;
      END MakeHeap;

    BEGIN
      row := 7;
      WAIT(Screen);
      SetCursorAt(1,row); WriteString('Heap Sort:');
      SetCursorAt(14,row); FOR i:= 0 TO HIGH(A2) DO Write(A2[i]); END;
      SEND(Screen);

      FOR i:= (HIGH(A2) DIV 2) TO 0 BY -1 DO
        MakeHeap(i,HIGH(A2));
      END;
      FOR i:= HIGH(A2) TO 1 BY -1 DO
        swap:= A2[0]; A2[0]:= A2[i]; A2[i]:= swap;
        WriteAt(row,14,A2[0]); WriteAt(row,14+i,A2[i]);
        MakeHeap(0,i-1);
      END;
      Croak;
    END HeapSort;

  (* Shell sort procedure ------------------------------------------*)

    PROCEDURE ShellSort;
      CONST NPASS = 4;
      VAR steps: ARRAY[1..NPASS] OF CARDINAL;
          step : CARDINAL;
```

```
      i,j  : CARDINAL;
      pass : CARDINAL;
      row  : CARDINAL;
      item : ItemType;
      exit : BOOLEAN;
BEGIN
  row := 9;
  WAIT(Screen);
  SetCursorAt(1,row); WriteString('Shell:    ');
  SetCursorAt(14,row); FOR i:= 0 TO HIGH(A3) DO Write(A3[i]); END;
  SEND(Screen);
                (* 'steps' contains decreasing increments for each *)
                (* pass. The last pass has increment 1.            *)
  steps[NPASS] := 1;
  FOR pass := NPASS-1 TO 1 BY -1 DO steps[pass]:= 2*steps[pass+1]; END;

  FOR pass := 1 TO NPASS DO
    step := steps[pass];
                (* Do a straight insertion sort with 'step' as *)
                (* an increment instead of 1.                  *)
    i:= step;
    WHILE i <= HIGH(A3) DO  (* Use WHILE instead of FOR because *)
                            (* loop increment is not a constant.*)
      item := A3[i]; j:= i; exit:= FALSE;
      LOOP
        IF (j < step) OR exit
          THEN EXIT;
          ELSE DEC(j,step); (* exit if decrement would set j < 0 *)
        END;
        IF (A3[j] > item)
          THEN A3[j+step]:= A3[j]
          ELSE A3[j+step]:= item;
               exit:= TRUE
        END;
        WriteAt(row,14+j+step,A3[j+step]);
      END; (* LOOP *)
      IF (NOT exit) THEN
         A3[0]:= item; WriteAt(row,14,A3[0])
      END;
      INC(i,step);
    END; (* WHILE i    *)
  END; (* FOR pass *)
  Croak;
END ShellSort;


(* Bubble sort procedure ------------------------------------------*)

PROCEDURE Bubble;
 VAR  i,j: CARDINAL;
      row: CARDINAL;
      temp: ItemType;
BEGIN
  row := 11;
  WAIT(Screen);
  SetCursorAt(1,row); WriteString('Bubble:   ');
  SetCursorAt(14,row); FOR i:= 0 TO HIGH(A4) DO Write(A4[i]); END;
  SEND(Screen);

  i:= HIGH(A4);
  WHILE (i > 0) DO
    j:= 0;
    WHILE (j < i) DO
      IF A4[j] > A4[j+1] THEN
```

```
          temp:= A4[j+1];
          A4[j+1]:= A4[j];
          A4[j]:= temp;
          WriteAt(row,14+j,A4[j]); WriteAt(row,14+j+1,A4[j+1]);
        END;
        j:= j+1;
      END;
      i:= i-1;
    END;
    Croak;
  END Bubble;

(* Merge sort procedure ------------------------------------------*)

PROCEDURE MergeSort;
   VAR
   i: CARDINAL;
   Q: ItemType;
   TempArray: Vector;
   Left, TopLeft, Right, TopRight, M, CurrentLength: CARDINAL;
   Count, Max: CARDINAL;
   row : CARDINAL;
BEGIN
   row := 13;
   WAIT(Screen);
   SetCursorAt(1,row); WriteString('MergeSort:');
   SetCursorAt(14,row); FOR i:= 0 TO HIGH(A5) DO Write(A5[i]); END;
   SEND(Screen);

   Max := HIGH(A5);
   CurrentLength := 1;
   WHILE CurrentLength < Max DO
      TempArray := A5;
      Left := 0;
      M := 0;
      WHILE Left<= Max DO
         Right := Left + CurrentLength;
         TopLeft := Right;
         IF TopLeft > Max THEN
            TopLeft := Max + 1;
         END;
         TopRight := Right + CurrentLength;
         IF TopRight > Max THEN
            TopRight := Max + 1;
         END;

         WHILE (Left < TopLeft)  AND (Right < TopRight) DO
            IF TempArray[Left] <= TempArray[Right] THEN
               A5[M] := TempArray[Left];
               WriteAt(row,14+M,A5[M]);
               Left := Left + 1;
            ELSE
               A5[M] := TempArray[Right];
               WriteAt(row,14+M,A5[M]);
               Right := Right + 1;
            END;
            M := M + 1;
         END;

         WHILE Left < TopLeft DO
            A5[M] := TempArray[Left];
            WriteAt(row,14+M,A5[M]);
            Left := Left + 1;
            M := M + 1;
```

```
            END;

            WHILE Right < TopRight DO
               A5[M] := TempArray[Right];
               WriteAt(row,14+M,A5[M]);
               Right := Right + 1;
               M := M + 1;
            END;

            Left := TopRight;
         END;

        CurrentLength := 2 * CurrentLength;
     END;
     Croak;
  END MergeSort;


BEGIN
   A1:= "ZzYyXxWwVvUuTtSsRrQqPpOoNnMmLlKkJjIiHhGgFfEeDdCcBbAa";
   A2:= A1; A3:= A1; A4:= A1; A5:= A1;

   ClearScreen;
   Init(Screen);
   SEND(Screen);

   SetCursorAt(1,20); WriteString('Starting sort processes -----');

   DefineProcess(Insertion, 1000);
   DefineProcess(HeapSort , 1000);
   DefineProcess(ShellSort, 1000);
   DefineProcess(Bubble   , 1000);
   DefineProcess(MergeSort, 1000);

   SetCursorAt(1,20); WriteString('Main procedure idle ---------');

   StartSystem;

   SetCursorAt(1,20); WriteString('Main procedure ending -------');

END Race.


DEFINITION MODULE vt100;
   (* EXPORT QUALIFIED ClearScreen, SetCursorAt; *)
   PROCEDURE ClearScreen;
   PROCEDURE SetCursorAt(Column, Row: CARDINAL);
END vt100.


IMPLEMENTATION MODULE vt100;

FROM InOut    IMPORT Write;

   VAR ASCIIOffset: CARDINAL;


   PROCEDURE ClearScreen;
      BEGIN
        Write(CHR(27)); Write('[');
        Write('2'); Write('J');
      END ClearScreen;
```

```
  PROCEDURE SetCursorAt(column, row: CARDINAL);
      BEGIN
        Write(CHR(13));
        Write(CHR(27)); Write('[');
        Write(CHR((row    DIV 10) + ASCIIOffset));
        Write(CHR((row    MOD 10) + ASCIIOffset));
        Write(';');
        Write(CHR((column DIV 10) + ASCIIOffset));
        Write(CHR((column MOD 10) + ASCIIOffset));
        Write('H');
     END SetCursorAt;

BEGIN
   ASCIIOffset := ORD("0");
END vt100.
```

Sorting Algorithm Race in occam

```
--
--  Sort Race in occam
--  Panos Papaioannou, The George Washington University, 1989
----
EXTERNAL PROC clear.screen :
EXTERNAL PROC goto.x.y (value x,y) :
EXTERNAL PROC num.from.keyboard (var n) :
EXTERNAL PROC num.to.screen.f (value n,d) :
EXTERNAL PROC str.to.screen (value rubbish[]) :
--
DEF high = 10 :
CHAN BubbleOut,LinearOut,finish1,finish2:
--
PROC Swap(VAR V[], VALUE i,j) =
  VAR Temp :
  SEQ
    Temp := V[i]
    V[i] := V[j]
    V[j] := Temp :
--
PROC delay =
  VAR count:
  SEQ
    count:=0
    SEQ i=[0 FOR 1000]
      count:=count+1 :
--
PROC LinearInsertionSort =
  VAR Top,Bottom,CurrentBottom,current,position,V1[high]:

  SEQ
    V1[0] := -3
    V1[1] := -1
    V1[2] := 1
    V1[3] := 2
    V1[4] := 3
    V1[5] := 6
    V1[6] := 0
    V1[7] := 9
    V1[8] := 8
    V1[9] := 10
    Top := 0
    Bottom := high
    SEQ  CurrentBottom = [Top FOR Bottom]
      SEQ
        current:=CurrentBottom
        WHILE ((Top) < current )
          SEQ
            IF
              V1[current] < V1[current-1]
                SEQ
                  Swap(V1, current, current-1)
                  LinearOut !  V1[0]          -- I Want the Screen
                  SEQ i=[1 FOR high-1]
                    LinearOut ! V1[i]
            current:=current-1
    finish1 ! TRUE:
--
--
```

```
PROC BubbleSort =
  VAR CurrentBottom,AnotherPassNeeded,Top,Current,V2[high]:

  SEQ
    V2[0] := -3
    V2[1] := -1
    V2[2] := 1
    V2[3] := 2
    V2[4] := 3
    V2[5] := 6
    V2[6] := 0
    V2[7] := 9
    V2[8] := 8
    V2[9] := 10
    Top := 0
    CurrentBottom := high
    AnotherPassNeeded := TRUE
    WHILE AnotherPassNeeded AND (CurrentBottom > 0)
      SEQ
        AnotherPassNeeded := FALSE
        SEQ Current = [Top FOR CurrentBottom-1]
          IF
            V2[Current+1] < V2[Current]
              SEQ
                Swap(V2,Current+1,Current)
                Bubbleout ! V2[0]          -- I Want the Screen
                SEQ i=[1 FOR high-1]
                  BubbleOut ! V2[i]
                AnotherPassNeeded := TRUE
        CurrentBottom := CurrentBottom - 1
    finish2 ! TRUE :
--

PROC ScreenController =
  VAR active1,active2,temp2[high],temp1[high] :
  SEQ
    active1:=TRUE
    active2:=TRUE
    WHILE  (active1) OR (active2)
      ALT
        BubbleOut ?  temp2[0]
          SEQ
            SEQ i=[1 FOR high-1]
              BubbleOut ? temp2[i]
            goto.x.y (5 ,5)
            SEQ i=[0 FOR high]
              SEQ
                delay
                num.to.screen.f(temp2[i],3)
        LinearOut ?  temp1[0]
          SEQ
            SEQ i=[1 FOR high-1]
              LinearOut ? temp1[i]
            goto.x.y (5,10)
            SEQ i=[0 FOR high]
              SEQ
                delay
                num.to.screen.f(temp1[i],3)
        finish1 ? ANY
          SEQ
            active1:= FALSE
            goto.x.y(5,11)
            str.to.screen(" LINEAR SORT FINISHED")
        finish2 ? ANY
```

```
          SEQ
            active2:= FALSE
            goto.x.y(5,6)
            str.to.screen(" BUBBLE SORT  FINISHED") :

--  MAIN
--
SEQ
  goto.x.y (5 ,4)
  str.to.screen(" BUBBLESORT ")
  goto.x.y (5 ,9)
  str.to.screen(" LINEARSORT ")
  PAR
    ScreenController
    LinearInsertionSort
    BubbleSort
```

Modula-2 Library Modules for Concurrent Programming

```
DEFINITION MODULE Process;

(* This module provides a simple set of concurrent process services  *)
(* including synchronization using binary semaphores.                *)

  (*EXPORT QUALIFIED DefineProcess,
                     KillProcess,
                     GoToSleep,
                     StartSystem,
                     SIGNAL,
                     Init,
                     SEND,
                     WAIT,
                     Awaited;*)
  TYPE
    SIGNAL;  (* Defines a binary semaphore. *)

  PROCEDURE DefineProcess( p: PROC; wssize: CARDINAL );
    (* Add a procedure to the list of procedures to be executed
       concurrently with the call to StartSystem.  The procedure p
       must be a parameterless procedure.  *)

  PROCEDURE Croak;
    (* Allows a process to terminates its own execution permanently. *)

  PROCEDURE GoToSleep;
    (* Allows a process to temporarily suspend its own execution. It
       is suspended and then immediately added to the run queue. *)

  PROCEDURE StartSystem;
    (* The procedures specified by previous DefineProcess calls are
       executed pseudo-concurrently. *)

  PROCEDURE Init( VAR s: SIGNAL );
    (* Initializes a user declared SIGNAL (semaphore). *)

  PROCEDURE WAIT( VAR s: SIGNAL );
    (* Issues a wait operation on the specified SIGNAL. *)

  PROCEDURE SEND( VAR s: SIGNAL );
    (* Issues a signal operation on the specified SIGNAL. *)

  PROCEDURE Awaited( s: SIGNAL ): BOOLEAN;
    (* Returns TRUE if there are processes WAITing on the specified SIGNAL.*)

END Process.

(* ---------------------------------------------------------------------- *)

IMPLEMENTATION MODULE Process;

(* This module provides a simple set of concurrent process services  *)
(* including synchronization using binary semaphores.                *)

  FROM SYSTEM IMPORT ADDRESS,     (* ADDRESS type *)
                     NEWPROCESS, (* Creates a process *)
                     TRANSFER;   (* Coroutine transfer of control *)
```

```
(* FROM System IMPORT Terminate; *) (* Terminate program, exit to DOS *)

FROM Storage IMPORT ALLOCATE;

FROM Queue   IMPORT Queue, (* type *)
       Qmakeempty, Qempty, Qinsert, Qremove, Qdefine;

FROM InOut IMPORT WriteString, WriteLn;

TYPE
  SIGNAL     = POINTER TO semaphore;

  semaphore = RECORD
                sent : BOOLEAN;
                procs: Queue
              END;

  processptr= POINTER TO ADDRESS;

VAR
  MAIN          : processptr;
  currentprocess: processptr;
  readyqueue    : Queue;

PROCEDURE deadlockhandler;
BEGIN
  WriteString('Deadlock has occurred');
  WriteLn;
  TRANSFER( currentprocess^, MAIN^ );
END deadlockhandler;

PROCEDURE Init( VAR s: SIGNAL );
BEGIN
  NEW(s);
  s^.sent := FALSE;
  Qdefine(s^.procs);
  Qmakeempty(s^.procs);
END Init;

PROCEDURE SEND( VAR s : SIGNAL);
  VAR prevprocess: processptr;
BEGIN
  IF NOT Qempty( s^.procs ) (* a process is waiting on semaphore *)
    THEN Qinsert( readyqueue, currentprocess);
         prevprocess := currentprocess;
         Qremove(s^.procs, currentprocess);
         TRANSFER( prevprocess^, currentprocess^);
    ELSE s^.sent := TRUE;
         IF NOT Qempty( readyqueue )
           THEN Qinsert( readyqueue, currentprocess);
                prevprocess := currentprocess;
                Qremove(readyqueue, currentprocess);
                TRANSFER( prevprocess^, currentprocess^);
         END
    END
END SEND;

PROCEDURE WAIT( VAR s: SIGNAL);
  VAR prevprocess: processptr;
BEGIN
  IF s^.sent
    THEN s^.sent := FALSE
    ELSIF NOT Qempty( readyqueue )
```

```
            THEN Qinsert( s^.procs, currentprocess);
                 prevprocess := currentprocess;
                 Qremove(readyqueue, currentprocess);
                 TRANSFER( prevprocess^, currentprocess^);
            ELSE deadlockhandler;
        END
    END WAIT;

    PROCEDURE Awaited( s: SIGNAL): BOOLEAN;
    BEGIN
      RETURN NOT Qempty(s^.procs);
    END Awaited;

    PROCEDURE DefineProcess( p: PROC; wssize: CARDINAL);
      VAR workspace  : ADDRESS;
          newprocess : processptr;
    BEGIN
      ALLOCATE( workspace, wssize);
      NEW( newprocess );
      NEWPROCESS(p, workspace, wssize, newprocess^);
      Qinsert( readyqueue, newprocess);
    END DefineProcess;

    PROCEDURE GoToSleep;
      VAR prevprocess : processptr;
    BEGIN
      IF NOT Qempty( readyqueue )
        THEN Qinsert( readyqueue, currentprocess);
             prevprocess := currentprocess;
             Qremove(readyqueue, currentprocess);
             TRANSFER( prevprocess^, currentprocess^);
        ELSE deadlockhandler;
      END;
    END GoToSleep;

    PROCEDURE Croak;
      VAR killedprocess : processptr;
    BEGIN
      NEW( killedprocess );
      IF NOT Qempty( readyqueue )
        THEN Qremove(readyqueue, currentprocess);
             TRANSFER( killedprocess^, currentprocess^);
        ELSE TRANSFER( killedprocess^, MAIN^);
      END;
    END Croak;

    PROCEDURE StartSystem;
    BEGIN
      IF NOT Qempty( readyqueue )
        THEN
          NEW( currentprocess );
          NEW( MAIN );
          Qremove( readyqueue, currentprocess );
          TRANSFER( MAIN^, currentprocess^ );
        END;
    END StartSystem;

  BEGIN (* Process module initialization *)
    Qdefine( readyqueue);
    Qmakeempty( readyqueue);
  END Process.
```

Queue Abstract Data Type in Modula-2

```
DEFINITION MODULE Queue;

(* This module exports a Queue abstract data type and the supporting  *)
(* queue services:                                                     *)
(* Qdefine    - Initializes a queue.     *)
(* Qmakeempty - Force a queue to empty.  *)
(* Qinsert    - Enqueue an item.         *)
(* Qremove    - Remove the next item from the queue *)
(* Qempty     - Is the queue empty?      *)

   FROM SYSTEM IMPORT ADDRESS;

   TYPE Queue;
   TYPE QueueItem = ADDRESS;

   PROCEDURE Qdefine(VAR Q: Queue);

   PROCEDURE Qempty(Q: Queue) : BOOLEAN;

   PROCEDURE Qinsert(VAR Q: Queue; Item: QueueItem);

   PROCEDURE Qmakeempty(VAR Q: Queue);

   PROCEDURE Qremove(VAR Q: Queue; VAR Item: QueueItem);

   VAR Qoverflow:  BOOLEAN;
       Qunderflow: BOOLEAN;

END Queue.

(* ------------------------------------------------------------------------ *)

IMPLEMENTATION MODULE Queue;

   FROM Storage IMPORT ALLOCATE, DEALLOCATE;

   TYPE Queue = POINTER TO QueueHeader;

        QueueBlockPtr = POINTER TO QueueBlock;

        QueueBlock  =
            RECORD
              item : QueueItem;
              next : QueueBlockPtr;
            END;

        QueueHeader =
            RECORD
              head: QueueBlockPtr;
              tail: QueueBlockPtr;
            END;

   PROCEDURE Qdefine(VAR Q: Queue);
   BEGIN
      ALLOCATE(Q,SIZE(QueueHeader));
      Q^.head := NIL;
      Q^.tail := NIL;
```

```
    END Qdefine;

    PROCEDURE Qmakeempty(VAR Q: Queue);
      VAR Qb: QueueBlockPtr;
    BEGIN
       Qb := Q^.head;
       Q^.head := NIL;
       Q^.tail := NIL;
       WHILE (Qb <> NIL) DO
         DEALLOCATE(Qb, SIZE(QueueBlock));
       END
    END Qmakeempty;

    PROCEDURE Qempty(Q: Queue) : BOOLEAN;
    BEGIN
       RETURN Q^.head=NIL;
    END Qempty;

    PROCEDURE Qinsert(VAR Q: Queue; Item: QueueItem);
      VAR Qb : QueueBlockPtr;
    BEGIN
      ALLOCATE(Qb,SIZE(QueueBlock));
      Qb^.item := Item;
      Qb^.next := NIL;
      IF Qempty(Q)
        THEN Q^.head := Qb;
        ELSE Q^.tail^.next := Qb;
      END;
      Q^.tail := Qb;
    END Qinsert;

    PROCEDURE Qremove(VAR Q: Queue; VAR Item : QueueItem);
      VAR Qb: QueueBlockPtr;
    BEGIN
       IF Qempty(Q)
         THEN Qunderflow := TRUE;
         ELSE Qb := Q^.head;
              Q^.head := Q^.head^.next;
              Item := Qb^.item;
       END;
    END Qremove;

END Queue.
```

Curriculum Modules (* Support Materials available)

CM-1 [superseded by CM-19]
CM-2 Introduction to Software Design
CM-3 The Software Technical Review Process*
CM-4 Software Configuration Management*
CM-5 Information Protection
CM-6 Software Safety
CM-7 Assurance of Software Quality
CM-8 Formal Specification of Software*
CM-9 Unit Testing and Analysis
CM-10 Models of Software Evolution: Life Cycle and Process
CM-11 Software Specifications: A Framework
CM-12 Software Metrics
CM-13 Introduction to Software Verification and Validation
CM-14 Intellectual Property Protection for Software
CM-15 Software Development and Licensing Contracts
CM-16 Software Development Using VDM
CM-17 User Interface Development*
CM-18 [superseded by CM-23]
CM-19 Software Requirements
CM-20 Formal Verification of Programs
CM-21 Software Project Management
CM-22 Software Design Methods for Real-Time Systems*
CM-23 Technical Writing for Software Engineers
CM-24 Concepts of Concurrent Programming
CM-25 Language and System Support for Concurrent Programming*

Educational Materials

EM-1 Software Maintenance Exercises for a Software Engineering Project Course
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